Parametric Evaluation of PRF Availability for a Space Borne SAR

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***Abstract*—The typical operation for Synthetic Aperture Radars (SARs) is to send out a pulse and receive the expected echoes before sending out the subsequent pulse. Space borne SARs normally have long working ranges, so they either need to extend the unambiguous range which significantly complicating the radar design and operation or operate with pulses 'in the air', that is, transmitting new pulses before the expected arrival of a previous pulse's echo, which is usually used to avoid range ambiguity. For a space borne SAR system, pulse repetition frequency (PRF) is an important parameter that affects and affected by other system parameters, analysis of this effect will be presented through the following paper in order to define the available PRF ranges with respect to chosen system parameters, the study will help system designer in determining the suitable SAR system parameters**

Keywords*— unambiguous range; pulse repetition frequency; range resolution; azimuth resolution

I. Introduction

Synthetic Aperture Radar (SAR) is a type of radar which is used in different weather conditions (clouds, fog or precipitation etc) and at different times (image can be acquired during day as well as night) and it is not used only to acquire a high resolution aerial and space based imaging of a terrain but also for different field of research [1].

SAR is a coherent radar which transmits microwave signals toward the targets and receives the backscatters from these targets as shown in figure 1.

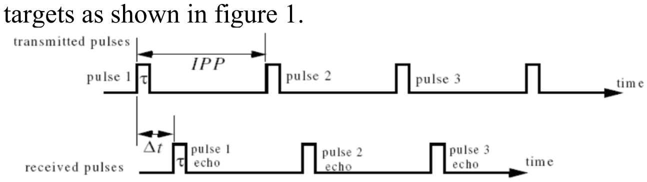

Fig.1. Pulse Repetition Interval and Frequency

SAR generates high resolution images using the magnitude and the phase of the returned signals. Figure 2 shows the side looking geometry of the SAR system.

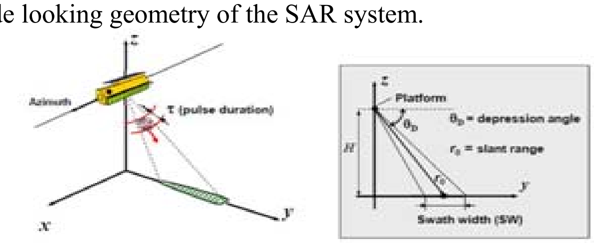

Fig. 2. Side Looking Geometry

An important issue in the design of the SAR system is the system carrier. Both the space borne and airborne are used as a carrier for the SAR systems [2], each one of them has its own advantages. The space borne carrier has the advantages that it can reach every area around the globe. On the other hand the airborne carrier has a low cost capability.

Different parameters are used to design the SAR system like point target signal to noise ratio (S/N), pulse repetition frequency (PRF), range resolution, azimuth resolution, data rate, synthetic aperture length and swath width [3, 4]. Taking an overview on these parameters a certain contradiction is detected as the antenna length should be short to improve the azimuth resolution at the same time a short wavelength is needed to avoid the aliasing of the complete aperture. The radar should be pulsed at an along-track distance of L/2 or shorter. Range resolution is improved by increasing the bandwidth and the bandwidth is limited by the speed at which the data is transmitted from the space borne to the processing station.

Ambiguities play an important part in all radar considerations. For all pulse Doppler radars ambiguities exist due to the periodical structures of the signals. This illuminates the fact, that the Pulse Repetition Frequency (PRF) will be a decisive factor. The principle Doppler frequency system received with periodically pulsed Doppler radar for moving platform is shown in Fig schematically.

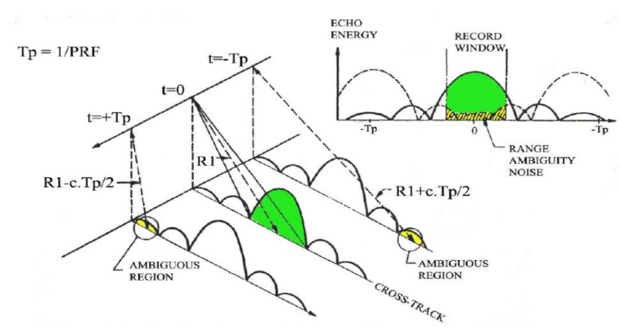

Fig. 3. Illustration of SAR range ambiguities [5]

For a space borne SAR, PRF (Pulse Repetition Frequency) is an important parameter that influences many other system parameters. Factors that affect PRF availability include radar velocity, antenna length, swath width, incidence angle, transmitter pulse length, and altitude. System parameters affected by PRF selection include peak transmitter power, duty factor, and raw data rate. In addition, due to PRF constraints, some combinations of swath width and antenna

length may be incompatible as the Nyquist requirement and the ambiguity constraints may conflict [3,4].

In this paper we focus on analysis of the relation between SAR system parameters and PRF and determining the available ranges for given system parameters.

The paper is structured as follows: in Section 2 short literature review about the PRF constraints is discussed. In Section 3, PRF parametric evaluation and its analyses charts are presented. In Section 4 the results of a system parameter design is presented. In section 5 the conclusion along with a discussion is given.

II. PRF Constraints

To achieve a high along track resolution (azimuth resolution), each time the radar carrier translates half of the long track antenna length, the radar sends a pulse to achieve the Nyquist sampling of the azimuth beam width. The lower bound of the PRF is presented in the following condition [6]:

$$PRF_{\min} = \frac{2\times RadarVelocity}{AzimuthAntennaLength} \tag{1}$$

Thus to improve the along track resolution, the along track antenna length is critical and hence the radar should pulse faster. Consequently to collect data in the across track resolution (range resolution), there is a less time between pulses.

Unfortunately the range ambiguity occurs if there are more than one pulse for given radar frequency found at time in the target zone,i.e. the maximum PRF would be determined by continuous reception of back to back pulses.

The swath width is set to be the upper bound of the PRF according to the following condition [7]:

$$PRF_{\max} = \frac{c}{2\times Swathwidth} \tag{2}$$

Swath width is the difference between the far and near slant ranges.
So from Equation (1) and Equation (2) the available PRF range is:

$$\frac{2\times RadarVelocity}{AntennaLength} \le PRF \le \frac{c}{2\times Swathwidth} \tag{3}$$

Where:

C is the speed of light in air (3×10^8 m/s).

A. Avoiding the Eclipsing (Blind ranges)

Not all PRFs between PRF min and PRF max are available. Due to the isolation problems inherent in radar systems, the receiver is blind during the transmit event. When the returning scene echo coincides with a transmit event, the received signal is said to have been eclipsed. PRFs that will result in eclipsing must be avoided; to avoid this condition the PRF must satisfy the inequality:

$$\frac{(N-1)}{(\tau_{near}-\tau_p)} < PRF < \frac{N}{(\tau_{far}+\tau_p)} \tag{4}$$

Where:

N are the whole numbers (1,2,3,..) corresponding to pulses.

τ_p is the transmitter pulse length.

τ_{near} is the round trip propagation time to the near edge of the swath.

τ_{far} is the round trip propagation time to the far edge of the swath.

$$\tau_{near} = \frac{2\times R_n}{c} \tag{5}$$

$$\tau_{far} = \frac{2\times R_f}{c} \tag{6}$$

Where:

R_n is the slant range to the near edge of the swath.

R_f is the slant range to the far edge of the swath.

PRFs which result in eclipsing depend on slant range to the near and far swath edges and the transmitter pulse width [8], [9].

B. Avoiding Nadir Returns

The returns from Nadir (near range) and fare range will be overlapped if the PRF is too large. These occurs at a time τ_{nadir} from the beginning of the transmit pulse.

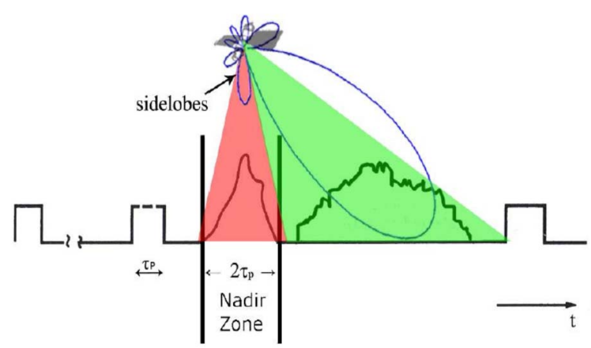

Fig. 4. Nadir interferences [5]

$$\tau_{nadir} = \frac{2.h}{c} \tag{7}$$

Where:

h…. is the altitude over the nadir point.

The near range echo is significantly stronger than the imaged fare range since the backscattering coefficient (σ) is larger for incidence angles near 0 degree. The duration of the near range echo is at least the length of the transmit pulse (tp) and for some terrain will last longer.
One solution to this approach is to avoid PRFs which cause a near range echo to arrive at the receiver at the same time as the fare range echo. Like the situation of the transmitter pulse eclipsing the fare range echo, the PRFs which avoid near range echoes coinciding with the fare range are described by an inequality:

$$\frac{(M-1)}{(\tau_{near}-\tau_p-\tau_{nadir})} < PRF < \frac{M}{(\tau_{far}+\tau_p-\tau_{nadir})} \tag{8}$$

Where:
M…. are whole numbers (1,2,3,...) corresponding to pulses.

III. PRF parametric analysis

SAR system parameters which determine PRF availability include:

- SAR altitude
- SAR velocity
- Resolution
- Antenna length
- Incidence angle
- Swath width.
- Transmitter pulse length.

PRF availability varies versus a single SAR parameter will be shown.

During system design parameters like altitude, center frequency, resolution are fixed and called baseline parameters depends on user requirement. Others such as antenna length, incidence angle, transmitter pulse length and swath width, are considered as variables.

The following system parameters are selected for the initial PRF parametric analysis for space borne SAR in a circular orbit:

TABLE I. INITIAL SYSTEM PARAMETERS VALUES.

Parameter	Value
Altitude	500 km
Resolution	3m
Incident angle	45 deg
Swath width	10 km
Pulse length	30 μs

There are limits for these unspecified parameters. For example, antenna length must be no longer than twice the desired one-look, azimuth resolution. Transmitter pulse length and PRF should be as large as possible to minimize peak transmitter power. It is desirable to make the swath width as large as possible, from a user's point of view. Incidence angle is strongly tied to system application. In some cases steep incidence angles (near nadir) maybe desirable, in others near grazing (shallow incidence angles) are desirable.

A. *PRF versus the Antenna length:*

The following Figure shows the effect of the antenna length variation from under 3m to 10m on the PRF availability as for all the antenna lengths, the PRF values that result in transmitter pulse eclipsing and nadir echo eclipsing are constant. The only PRF design constraint that varies with antenna length is PRFmin which relates to the requirement on adequately sampling the Doppler bandwidth of the signal.
Also, as the PRF increases, the ranges of available PRFs shrink to nothing. For the baseline system, this figure also shows the lower bound on the usable PRFs that varies as a function of antenna length.

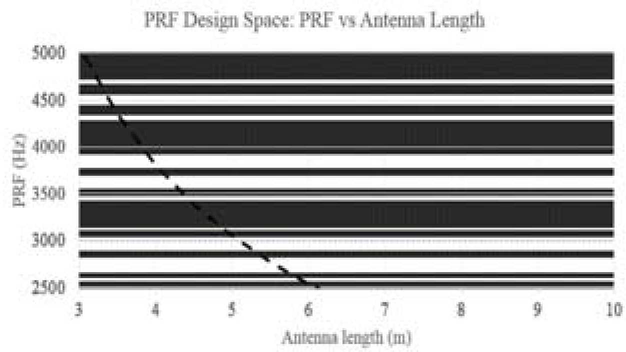

Fig. 5. PRF vs. Antenna Length.

B. *PRF versus the Transmitter pulse length*

The following Figure shows the PRF availability versus Transmitter pulse length. The upper bound of the PRFmax decreases with the increasing of the transmitter pulse length. The bands of PRF unavailability due to transmitter pulse eclipsing and nadir echo eclipsing broaden with the increasing of the transmitter pulse length. It's clear that pulse lengths larger than 100 μs are unusable.

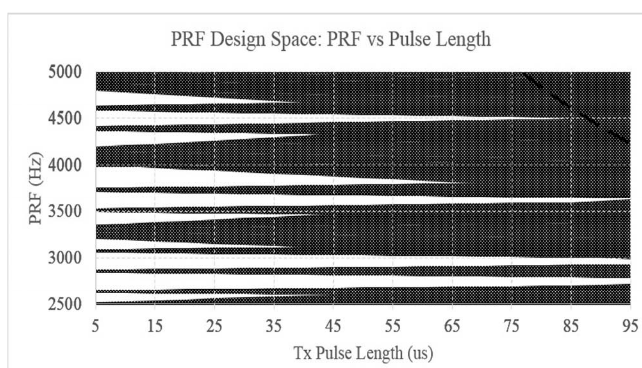

Fig. 6. PRF vs. Transmitter Pulse Length.

C. PRF versus the Swath Width:

The relationship between PRF availability and swath width on the ground is shown in 7.The PRFmax decreases with increasing of the swath width as well as the transmitter pulse length relation. The bands of PRF unavailability due to transmitter pulse eclipsing and nadir echo eclipsing are broad with increasing of the swath widt

For 50 km and larger, there are no PRFs available to support the swath widths.

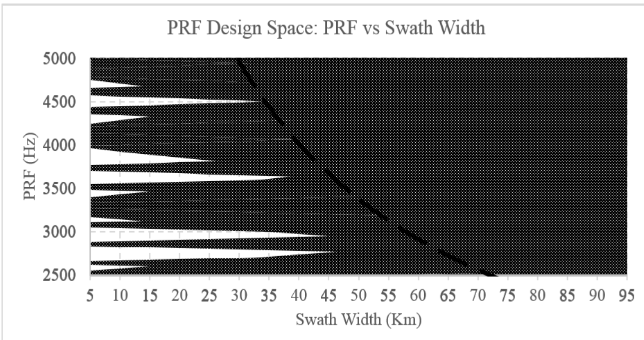

Fig. 7. PRF vs. Swath Width (on ground).

D. PRF versus the Altitude

The variations in radar altitude effect on PRF availability is shown in Fig. . For 500 km altitude the appropriate PRF is not appropriate for the altitude of 480 km.

So for the altitude variations (due to non-circular orbit, orbit decay, variations in elevation of the target) a new PRF should be supposed.

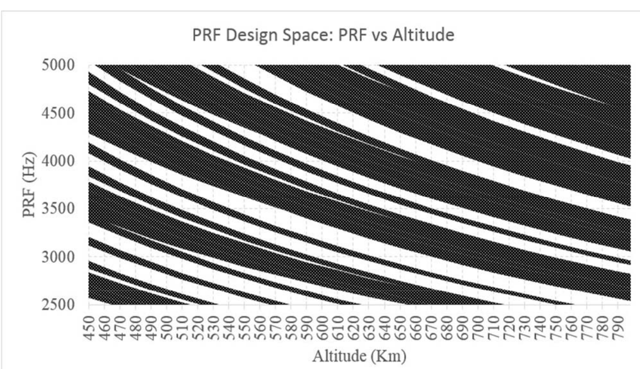

Fig. 8. PRF vs. Altitude.

E. PRF versus the Incidence angle

The effect of incident angle variations on the PRF availability is shown in Fig. . The incident angle has a great influence on PRF availability, a small change of the incident angle constrains the available PRF.

For an incident angle more than 65 degrees, there are no PRFs are available.

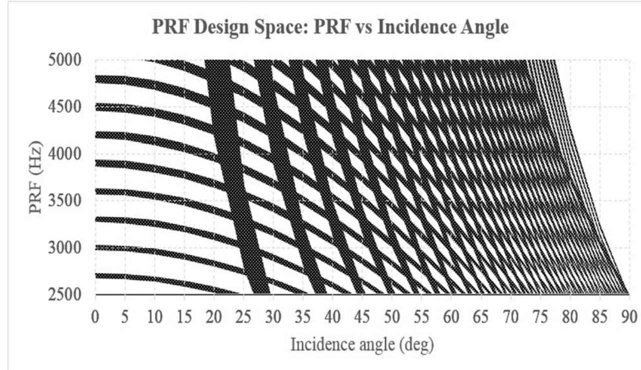

Fig. 9. PRF vs. Incidence Angle.

F. PRF versus the Look angle

Look angle is the pointing angle of the antenna measured from nadir of the radar. The effect of the look angle on the PRF availability is shown in Fig.

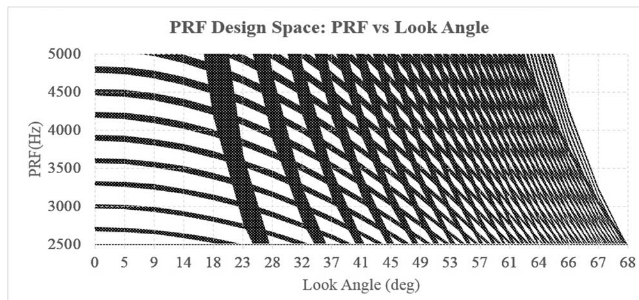

Fig.10. PRF vs. Look Angle.

For look angle more than 60 degrees, there are no PRFs are available.

J. Relationship between look angle and incidence angle

The relationship between look angle and incidence angle at various altitudes is shown in Fig. .

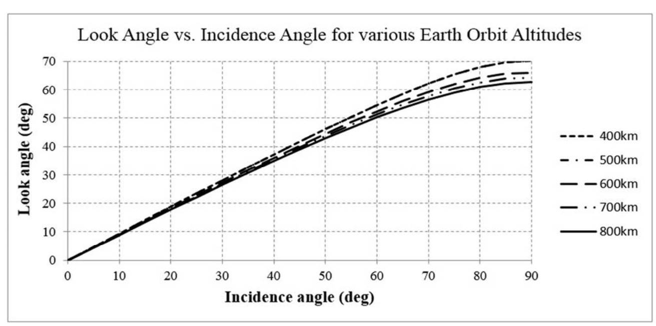

Fig. 11. Look Angle vs. Incidence Angle at various altitudes.

They are nearly the same at low altitudes, but, as the altitude

increases the difference becomes significant especially at high values.

IV. Results

Based on the parameters in **table II**, the available PRF ranges are stated in table 2 with its rank.

TABLE II. RANGES OF THE AVAILABLE PRF

Available PRF ranges		Rank
From	*To*	
2570	2604	12
2666	2821	13
2889	3038	14
3111	3139	15
3427	3473	16
3555	3690	17
3777	3907	18
4284	4341	20
4444	4558	21
4666	4709	22
5141	5209	24
5333	5426	25
5999	6077	28
6222	6278	29
6888	6945	32
7777	7813	36

Rank is the number of transmitted pulses after which the echo is received.

Generally, the azimuth ambiguity gets better as PRF increases. So the available PRF should increase from above values, until the azimuth ambiguities-to-signal ratio (AASR) is acceptable.

The PRF in chosen with oversampling factor which usually equals 1~ 1.5 over the minimum PRF, trying to keep the sampling frequency as low as possible.

V. Conclusion

The dependency of usable PRFs on the radar system parameters has been shown. It was also, shown that the lower bound on the PRF needed to adequately sample the Doppler bandwidth is radar frequency independent, but is dependent on antenna length, which is related to azimuth resolution in strip map operating mode.

To analyze eclipsing of the scene echo by the transmitted pulse and the nadir echo, timing calculations were presented and the results were shown graphically. The effects of variations of each of the various system parameters were presented.

A reasonable PRF value will be selected that avoids eclipsing and oversamples the Doppler bandwidth of the scene echo and allows a margin of error in antenna pointing and altitude values.

For a non-circular orbit the acquisition geometry is changing depending on the satellite position in the orbit, so for the same system parameters the PRF value needs to be changed accordingly.

However, the SAR ambiguities are not only controlled by the waveform (represented by PRF for instance) but also by antenna pattern.

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